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QUARTERLY REPORT

State and National Energy and
Environmental Risk Analysis
Systems for Underground
Injection Control
DE-AC22-92MT92004

July 15, 1994
Report No. PRDA 82-2
Report Period: 4/1/94 - 7/31/94

ICF Resources Inc.
9300 Lee Highway
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Contract Period: 5/1/92 - 8/31/94

I. Contract Objective

No change.

II. Technical Approach Changes

A revision to the Statement of Work for the project was received during the fourth quarter of 1993. It discontinued work on Task 1 (other than presentation of work completed to date) and adds slightly to the work to be completed under Task 2. Task 3 also changed to reflect the modifications to Tasks 1 and 2.

III. Task Order I

A. Objective

This task has been discontinued.

B. Activity Report

April - July: The deliverable required under the new Statement of Work to summarize the work completed on Task 1 prior to its discontinuation was drafted.

C. Specific Items Delivered During This Period

None.

D. Problem Areas

None.

E. Work Planned for Next Period (July 1 - September 30, 1994)

The draft report summarizing work completed on this task prior to the change in the Statement of Work will be finalized and delivered to DOE. All other work on this task has been discontinued.

IV. Task Order II

A. Objective

This task involves developing a preliminary national energy and environmental risk analysis system (EERAS). An analytical methodology for nationwide estimation of potential for USDW contamination from underground injection and the current and future resource potential associated with these areas of concern will be developed.

B. Activity Report

April: Limited work was completed this month.

May: GSAM development and database are finally defined sufficiently to determine necessary tasks to make EERAs compatible with it. Began implementing modifications required in locational cross-reference file to make system compatible with GSAM as well as TORIS.

June: Continued modifications to locational cross-reference file, including development of "pseudo" codes for TORIS reservoirs that are compatible with GSAM reservoir numbering scheme.

C. Specific Items Delivered This Period

None.

D. Problem Areas

None.

E. Work Planned for Next Period (July 1 - September 30, 1994)

A three-month, no-cost extension to the period of performance (until November 30, 1994) is being requested.

Modifications to the locational cross-reference file to assure GSAM compatibility will be completed. The database prototype and input of UIC-related data will also be completed. The methodology for national-level analysis of the potential contamination of USDWs from Class II injectors will be developed. EERAS will be documented and additional development options will be characterized.

V. Task Order III

A. Objective: Technology Transfer

The technology transfer efforts includes reports, presentation, and papers for the purpose of communicating research results to specific audiences. The technology transfer activities related to Task 1 were discontinued by the change in the Statement of Work.

B. Activity Report

April - June: At a June 16th meeting held at DOE/METC on a related project (which builds on the database concepts developed under this contract), discussions were held with DOE personnel from MSO, METC, and OGPT regarding possible uses for a system like EERAs. The insight gained at this meeting will be reflected in the characterization of future development options as required under the contract.

C. Specific Items Delivered This Period

None.

D. Problem Areas

None.

E. Work Planned for Next Period (July 1 - September 30, 1994)

Technology transfer efforts during the next quarter will be somewhat limited. They will consist primarily of continued discussions with various DOE personnel (different offices) about EERAS and the features required to make it useful for their needs. These discussions will focus more on the potential of the full development of EERAS (for required deliverable) rather than on the prototype version being constructed under this contract.

Glenda E. Smith
Project Manager

Availability of Data to Support Class II Risk Assessment Protocol

Prepared for

U.S. Department of Energy
Metairie Site Office

Contract: DE-AC22-92MT92004

Prepared by

ICF Resources Incorporated

August 1994

Availability of Data to Support Class II Risk Assessment Protocol

Background

The U.S. Department of Energy (DOE) has recognized the importance of state information management systems in understanding and cost-effectively addressing potential environmental problems resulting from oil and gas exploration and production activities. One advantage of implementing and enforcing environmental regulations at the state level is the ability to tailor requirements to the risks posed on a site-specific basis. However, this site-specific tailoring can require substantial amounts of environmental and operational data, which must be readily available to regulators in determining applicable requirements.

Based on this recognition, over the past few years, DOE's Oil Research Program has pursued efforts to assess current information management systems at the state level, methods for improving these systems, and development of techniques to facilitate "risk-based" data management to support regulatory decision-making. As part of these efforts, ICF Resources (ICFR) received a contract (DE-AC22-92MT92004) that included a task to assist states in the development of a risk assessment protocol for Class II injection wells. The scoping of a methodology for development of this protocol was completed and presented at the Class II Injection Well Management and Practices Symposium. A copy of the paper describing this methodology is included in the appendix.

Following this Symposium, several factors interacted to curtail further efforts toward the development of this risk assessment methodology. The primary factor was the initiation of a process by the American Petroleum Institute (API) and the Ground Water Protection Council (GWPC) to develop a variance plan methodology that could be used to identify areas of a state where Class II injection operations pose little risk of groundwater contamination. These areas would be granted variances from area-of-review requirements under anticipated changes to the Class II underground injection control (UIC) regulations. Since this process had the support of both industry and the states, it was determined that continuation of ICFR's activities to develop a risk assessment protocol could result in duplication of effort.

Prior to receiving a change to the contract statement of work deleting further work on the development of the risk assessment protocol, effort was invested in identifying potential sources of data and data availability for the items identified as part of the protocol. The purpose of this paper is to document these efforts for reference by any future activities directed to the development of risk assessment tools for Class II injection well management.

Potential Risk Assessment Data Requirements

The risk assessment protocol concept was based on the identification of potential contamination pathways from Class II wells and the risk assessment factors associated with each pathway. Figure 1 presents a matrix illustrates the potential contamination pathways identified. Movement of produced water from the target injection zone of a Class II well to a drinking water aquifer could occur either outside or inside the well casing. The factors associated with each of these would be dependent upon whether the well was a disposal well, a production or injection well, or an abandoned well. An uncased abandoned well could be considered as falling in either of the bottom cells in the matrix shown in Figure 1, with the factors altered to reflect absence of cement or casing rather than casing failure.

Figure 1
Universe of Potential Contamination Pathways

	Outside Casing (Cement Failure)	**Inside Casing (Casing/Tubing Failure)**
Disposal Well		
Production/Injection (EOR) Well		
Abandoned Well		

The six cells shown in Figure 1 describe the potential pathways for produced water to reach and contaminate a drinking water aquifer. A number of factors would affect whether contamination could occur through each pathway identified. Some factors would be common to all cells of the matrix, while others would be unique to a single cell. Table 1 provides a preliminary list of the factors associated with each cell of the matrix. Ultimately a risk assessment methodology would probably utilize only a portion of these factors, but in determining which factors to use, it is important to broadly consider what factors may affect risk.

Table 1
Major Risk Factors for Each Potential Contamination Pathway

Contamination from Outside Casing in a Disposal Well

- Pressure in disposal formation
  - Depth
  - Volume of injected fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and disposal formation
- Quality of cement job
  - Age of well
  - Hole size and casing size
  - Formation type
  - Type and volume of cement pumped
  - Pressure test results (direct measure of communication)
  - Cement bond log results (direct measure of micro-annulus or channeling)
- Number/density of disposal wells

Contamination from Outside Casing in a Production or Injection Well

- Pressure in injection formation
  - Depth and/or degree of over or under pressure (if any)
  - Volume of injected fluids or produced fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and producing formation
- Quality of cement job
  - Age of well
  - Hole size and casing size
  - Formation type
  - Type and volume of cement pumped
  - Pressure test results
  - Cement bond log results
- Number/density of production or injection wells

Table 1 (Continued)
Major Risk Factors for Each Potential Contamination Pathway

Contamination from Outside Casing in an Abandoned Well

- Pressure in disposal/injection zones penetrated by abandoned well
  - — Depth
  - — Volume of injected fluids
  - — Capacity of formation (kh)
- Pressure in USDW
  - — Depth
  - — Degree of depletion/recharge
- Vertical distance between USDW and disposal/injection formation
- Abandoned well characteristics
  - — Age
  - — Plugging/casing/completion practices
  - — Plugging materials
- Quality of cement job
  - — Age
  - — Hole size and casing size
  - — Type and volume of cement pumped
  - — Pressure test results
  - — Cement bond log results
- Number/density of abandoned wells
- Distance from disposal/injection well

Contamination from Inside Casing in Disposal Well

- Pressure in disposal formation
  - — Depth
  - — Volume of injected fluids
  - — Capacity of formation (kh)
- Pressure in USDW
  - — Depth
  - — Degree of depletion/recharge
- Vertical distance between USDW and disposal formation
- Completion configuration
  - — Tubingless or packerless
    - Number of casing strings
    - Age of well
    - Production history (pressure, sand, rates)
    - Produced fluid corrosivity (CO_2, H_2S)
    - USDW water composition
    - Casing strength, material, condition (new or used), size
  - — Tubing and packer
    - All factors identified for tubingless or packerless
    - Tubing strength, material, condition (new or used), size
    - Packer type
    - Type of annular fluid
  - — Annular disposal
    - All factors identified for tubing and packer
    - Surface pressure on annulus/injection rate
- Use of cathodic protection
- Number/density of disposal wells

Contamination from Inside Casing in Production or Injection Well

- Pressure in injection formation
  - — Depth and/or degree of over or under pressure (if any)
  - — Volume of injected fluids
  - — Capacity of formation (kh)
- Pressure in USDW
  - — Depth
  - — Degree of depletion/recharge
- Vertical distance between USDW and injection formation

Table 1 (Continued)
Major Risk Factors for Each Potential Contamination Pathway

Contamination from Inside Casing in Production or Injection Well (Continued)

- Completion configuration
  - — Tubingless or packerless
    - Number of casing strings
    - Age of well
    - Production history (pressure, sand, rates)
    - Produced fluid corrosivity (CO_2, H_2S)
    - USDW water composition
    - Casing strength, material, condition (new or used), size
  - — Tubing and packer
    - All factors identified for tubingless or packerless
    - Tubing strength, material, condition (new or used), size
    - Packer type
    - Type of annular fluid
  - — Annular disposal
    - All factors identified for tubing and packer
    - Surface pressure on annulus/injection rate
- Use of cathodic protection
- Number/density of production and injection wells

Contamination from Inside Casing in Abandoned Wells

- Pressure in disposal or production zones penetrated by abandoned well
  - — Depth
  - — Volume of injected fluids
  - — Capacity of formation (kh)
- Pressure in USDW
  - — Depth
  - — Degree of depletion/recharge
- Vertical distance between USDW and disposal or production formation
- Abandoned well characteristics
  - — Age
  - — Plugging/casing/completion practices
  - — Plugging materials
  - — Annular fluid
- Corrosion potential
- Number/density of abandoned wells
- Distance from disposal or injection well

Potential Data Sources and Availability

Current state UIC information management systems are the logical starting point for obtaining the data needed to conduct a risk assessment of Class II wells. The Ground Water Protection Council (GWPC), as part of a grant from DOE, conducted an assessment of current state information management systems and the availability of certain types of data. This document, entitled "Phase I Inventory and Needs Assessment of 25 State Class II Underground Injection Control Programs," provides an excellent reference on the current availability of certain data items (e.g., surface casing depth, injection zone depth) and whether these data are currently stored in paper or electronic form. The GWPC found that most current state UIC information systems do not contain many of the key data items for conducting risk-based assessments. Only 9 of the 25 states studied have systems that include any risk capability, and these can evaluate risk only to a limited extent.

Another key potential data source was perceived to be oil companies. ICFR personnel spoke with representatives of several major oil companies about their ability to provide data, particularly for wells that had a mechanical integrity failure, but no contamination of groundwater occurred. It is conceivable that such data could provide meaningful clues to the importance of various factors in determining the risk to groundwater. Unfortunately, oil company personnel indicated that it could be difficult for them to extract the desired information due to the nature of company operations. Most companies would discover a mechanical integrity failure as part of a routine well workover operation and correct the problem as part of that operation. Consequently, the records would be kept with all of the other records on routine maintenance operations in a particular field. No special file indicating mechanical integrity failures is kept. This would make it difficult for a company to identify wells that had problems and provide that data to this effort.

Some states currently have information management systems that can supply certain risk-based data or have recently directed efforts at studying potential problems related to underground injection. These states were also contacted to determine the extent of information available and whether it could be used to support the type of risk assessment protocol that has been envisioned. Texas and Oklahoma were contacted about the information they might have available, even that in paper form or based on special studies. While each could provide data for some of the factors from Table 1, neither has in accessible form sufficient information of the type sought to evaluate the relative importance of the various factors that could affect risk potential.

Given these difficulties in obtaining a single source for the data needed, ICFR developed the matrix shown in Table 2 to identify possible data sources or analogs that may be able to be developed. Published data are rarely available for many of the items, but state personnel may be able to rely on their expertise or work with companies to develop the data needed for risk analysis.

Conclusions

Developing a risk assessment protocol that meets the dual objectives of being able to make areal assessments and operate on a limited amount of readily available information would be a difficult task. In the absence of specific data, numerous assumptions based on the expertise of state or company personnel familiar with operations in an area could be required. Development of the protocol would require significant testing to determine how sensitive the results were to these assumptions, with additional data investigation or calibration focused in the areas of greatest sensitivity.

The benefits of using a risk-based approach are significant. Not only could such a tool assist states in providing analysis to support a variance program for Class II injection wells, it could help the state to allocate its limited personnel resources to focus on those areas that potentially pose the greatest risk. Operators would also benefit from states using a risk-based approach, since they would be required to incur costs for added protective measures only in those areas where they are needed. In areas where standard operating practices provide sufficient protection, no additional costs would be incurred. This could help to prolong the productive life of producing and injection wells and increase the total volume of oil or gas produced.

Table 2
Potential Data Sources for Various Risk Factors

Risk Factor	Potential Sources or Analogs
Depth of injection/disposal formation	Injection well records; state or company files
Volume of injected/produced fluids	Injection/production well records; state or company files
Formation capacity	Injection well permits; state or company files; special studies
Location of USDWs and degree of depletion/recharge	State records; state geological survey; U.S. geological survey; water well records; special studies
Age of well	State or company records; date of field discovery (EIA)
Hole size and casing size	Well permit records; typical practice
Formation type	Well permit records; geological studies; state geological survey; U.S. geological survey
Type and volume of cement pumped	Cementing records; state or company files; typical practice
Cement integrity	Pressure test; cement bond log tests; state or company files
Number/density of wells in area; distance from abandoned well to injector or producer	State records; results of prior "area of review" analyses; Gruy (1989), and other studies conducted as part of Mid-Course Evaluation of Class II wells
Plugging/casing/completion practices; plugging materials	State or company records; typical practices over time; expertise of engineers in area
Well construction	State or company records; typical practices within area; Gruy (1989), and other studies conducted as part of Mid-Course Evaluation of Class II wells
Production history	State or company records; commercial databases such as Dwight's or Petroleum Information Corp.
Use of cathodic protection	Michie (1988); state or company records
Produced fluids corrosivity	Michie (1988); company records; special studies

Appendix

CLASS II RISK ASSESSMENT PROTOCOL

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Abstract

Substantial volumes of brine, produced in conjunction with oil and gas, are reinjected to underground formations. Underground injection control (UIC) programs have been established under the authority of the Safe Drinking Water Act to protect underground sources of drinking water from contamination by subsurface injection. Managing the risks of contamination from injection operations is an important objective of state UIC programs.

Limited budgets often constrain state efforts to improve the quality and quantity of information available for the management of potential contamination risks from underground injection. Decisions on where to concentrate state resources in data management and field enforcement are often made subjectively. A risk assessment tool which explicitly characterizes the risk of contamination from injection operations can assist states in identifying and justifying regulatory and enforcement priorities. This paper describes the development process for a risk assessment protocol to explicitly characterize these risks which is compatible with existing data management programs and can be adapted for use by the states.

The *absolute* risk of groundwater contamination due to underground injection is quite low, often discussed in terms of occurrences per million well-years. In setting priorities, the *relative* risk of contamination of one area versus another area is more important than the absolute risk. The risk protocol to be developed will focus on the relative risk of contamination among various areas within a state.

The characterization of contamination potential from Class II injection wells involves:

- Identification of potential contamination pathways
- Definition of the factors affecting risk of contamination for each pathway
- Identification of possible data sources or analogs for each risk factor
- Characterization of the comparative importance of each factor affecting risk
- Computation of the relative risk of contamination.

Previous UIC-related risk assessments have focused on a single contamination pathway. The risk assessment protocol to be developed will incorporate alternative pathways in a comprehensive assessment of the potential risks.

The risk assessment protocol will be developed and tested with the assistance of state regulators. It will be based on commercial software and will provide explicit documentation of all assumptions, with the flexibility to adapt these assumptions to differing conditions. Development and testing of the risk assessment protocol is expected to be complete by April 1993.

A risk assessment protocol for characterizing the relative risk of groundwater contamination from Class II injection operations provides an explicit basis for incorporating risk-based decision-making into current state regulatory and data management programs. The benefits generated from use of an explicit methodology include prioritizing and justifying state activities, such as increased field activity monitoring, inclusion of fields in a computerized data management system, and collection of additional injection or production-related information.

Introduction

Oil and gas exploration and production (E&P) activities result in large volumes of produced brine that must be managed and disposed. Over 90% of this produced brine is currently reinjected into underground formations through Class II injection wells (Wakim, 1987). Two-thirds of this brine is reinjected to producing formations for pressure maintenance and enhanced recovery operations. The remainder is injected in saltwater formations below the base of the deepest potentially usable drinking water aquifers. Class II injection operations are regulated under the authority of the Safe Drinking Water Act (SDWA), which establishes minimum requirements for underground injection control (UIC) programs. UIC requirements were established to protect underground sources of drinking water (USDWs) from endangerment by subsurface emplacement of fluids. Twenty-two states currently have primacy for UIC operations; regional offices of the Environmental Protection Agency (EPA) administer UIC programs in the remaining states.

Need for Risk Assessment Protocol

Managing the risks associated with oil and gas injection operations requires substantial volumes of information about injection well operations, the history of well integrity testing, and geologic and hydrogeologic conditions. States are making substantial strides in the management of this UIC data, as recent and ongoing efforts demonstrate. However, limited budgets often constrain state efforts to improve both the quantity and quality of information available. Decisions on where to concentrate state resources, in the areas of both data management and field enforcement, are often made subjectively, based on anecdotal information or "experience." An explicit methodology for characterizing the relative risks of groundwater contamination from underground injection can assist states in optimizing the use of their limited resources and in establishing and justifying regulatory and enforcement priorities.

In 1989, EPA conducted a Midcourse Evaluation of UIC requirements under the SDWA, which identified several areas for further investigation. EPA convened a Class II Injection Well Advisory Committee to make recommendations about required program improvements. In early 1992, the Advisory Committee made its recommendations, which EPA will consider for rulemaking over the next 18-24 months.

One of the recommendations of the Advisory Committee was to extend the current area of review (AOR) requirements to Class II wells previously permitted by rule that have not already been covered by an

AOR. The Committee recommended that states be allowed to establish a variance program for identifying areas where there is a sufficiently low risk of upward fluid movement from the injection zone that could potentially endanger USDWs. Wells granted a variance would be exempted from those AOR requirements. The Committee indicated that in establishing a variance program, states could consider:

- The absence of USDWs
- Whether the reservoir (injection zone) is underpressured relative to the USDW
- Whether local geological conditions preclude upward fluid movement that could endanger USDWs
- Other compelling evidence.

A risk assessment protocol can be used by states to provide an explicit basis for setting up a variance program, as well as for prioritizing state regulatory activities on the basis of relative risk.

The Underground Injection Practices Research Foundation (UIPRF) is currently sponsoring efforts to evaluate and assist current state UIC data management efforts. In the *Phase I Inventory and Needs Assessment* (CH2M Hill, 1992), state regulators contacted generally ranked "risk assessment and evaluation" and "determination of high-risk areas throughout the state" as high priorities. The risk assessment protocol to be developed addresses these issues and will be compatible with existing data management programs and risk assessment efforts.

Purpose of Paper

The purpose of this paper is to describe the objectives and preliminary design of a protocol to assess the relative risk associated with UIC operations. The work on which this paper is based is being sponsored by the U.S. Department of Energy (DOE), Metairie Site Office and is being performed by ICF Resources Incorporated. This project is on-going, and the design phase of the risk assessment protocol is just being completed.

Importance of Relative Risk

While casing corrosion and other mechanical integrity failures in injection wells sometimes occur, groundwater contamination as a result of these problems is extremely rare. The General Accounting Office (GAO) has reported finding 23 cases since 1970 where Class II injection operations are believed responsible for contamination of a drinking water aquifer (GAO, 1989). This compares with over 160,000 active Class II injection wells nationwide. Nine of the cases reported by GAO resulted from purposeful injection directly into a USDW, which would be a violation of existing law. Only a small number of reported occurrences of contamination are believed to be due to mechanical integrity failure or abandoned wells serving as a conduit for contaminants. In an earlier study based on data from Texas in the early 1970s, the Office of Technology Assessment (OTA) estimated that contamination had occurred only 2 times per 1 million well years (OTA, 1978).

Federal UIC program changes from the mid-1980s have been followed by increasing requirements at the state level. The implementation of new UIC requirements, by eliminating some of the prior problems and strengthening protection, has reduced the risk of future groundwater contamination below the levels observed by GAO and OTA. Thus, in absolute terms, the risk of groundwater contamination from Class II injection operations is quite low.

In establishing a variance program for AOR requirements or for prioritizing state regulatory efforts, the *relative* risk is more important than the *absolute* risk of contamination. Even an older producing area with numerous inadequately plugged abandoned wells and highly corrosive subsurface conditions is unlikely to have an occurrence of groundwater contamination due to injection. But the relative risk of such an area compared with an area discovered and developed after 1984 may be considerably higher. In allocating its limited resources, a state could reduce the potential that groundwater contamination would occur by focusing, in relative terms, on areas with the greater risk. The priority in this example is fairly obvious. But in many states the differences among fields will be painted in numerous shades of gray, and an explicit means for estimating the relative risk of contamination could assist in identifying and justifying priorities.

Previous Work on Risk Assessment from UIC Operations

Several previous analyses assessing the risk of groundwater contamination from Class II injection have been performed, including:

- Michie for API (1988)
- Michie for UIPRF (1989 and 1991)
- ICF Incorporated for EPA (1990)
- Warner and McConnell for API (1990).

Each of these analyses has expanded the knowledge base for estimating the risks associated with injection and the factors which contribute to that risk.

Michie's work for the American Petroleum Institute (API) resulted in a methodology for estimating the absolute risk of contamination if simultaneous failure of the tubing, production casing, and surface casing occurred. The methodology used historical data on casing and tubing failure rates and accounted for the corrosive potential of subsurface water in producing basins. This methodology confirmed that the absolute risk of groundwater contamination is quite low.

For the UIPRF, Michie linked his risk assessment methodology with a UIC data management system for the Williston Basin in North Dakota, South Dakota and Montana. Incorporating risk assessment with a data management system, this project demonstrated the utility of risk-based data management for UIC programs. Michie took this concept one step further in a project in Kansas sponsored by UIPRF, which included both producing and injection wells in the data management system.

ICF Incorporated developed a methodology for EPA that performed area-wide assessments of the risk of USDW contamination from abandoned wells in the vicinity of injection operations. The methodology considered such factors as the pressure differential, permeability, injection rate, radius of concern, and probability that an abandoned well existed within the radius of concern. The methodology resulted in a qualitative assessment of low, medium, or high risk. This methodology was field tested in Oklahoma and reviewed by the oil and gas industry, but project funding was discontinued before completion.

Warner and McConnell also focused on abandoned wells as potential pathways for groundwater contamination. They used finite differential numerical modeling to determine the extent to which brine might be forced into a USDW. This analysis included a detailed examination of wells in the Lower Tuscaloosa Sand of Mississippi and Louisiana. Modeling was based on scenarios of an uncased abandoned well and a cased abandoned well with casing corrosion. The analysis concluded that abandoned wells in this area were highly unlikely to serve as conduits for brine to reach USDWs.

Objectives of Risk Assessment Protocol

Building from this work, a protocol will be developed that can help better characterize the relative risk of contamination for use in allocation of limited resources, justification of a variance program, or other risk-based decision-making. The system's expected (and potential) applications define several general requirements/objectives:

- Areal Assessments. The protocol should perform areal assessments of the relative risk of contamination. In setting priorities, assessments of areas (such as a field) are more useful for high level appraisals than assessments of individual wells. However, to provide a high degree of confidence in the result, the area to be considered must be relatively homogeneous; areas larger than a field may be impractical. The methodology may also be applicable to an individual well, to assist in identifying potential concerns within high priority areas.

- Coverage. The protocol should incorporate the risk from as many potential contamination pathways as possible to provide a comprehensive assessment of the relative risk of groundwater contamination via different pathways within an area.

- Data Requirements. The protocol should require a minimum amount of readily available data to maximize the utility of the system to state regulators. Yet, where more data are available, the protocol should accommodate this information, improving the degree of confidence associated with the result.

- Explicit Assumptions. Any assumptions included in the protocol should be made explicit, and means should exist for the regulator to adjust these assumptions based on additional information, differing conditions, or to test sensitivities.

- Adaptability. While a single system cannot be developed that readily meets the needs of regulators in all producing states, the protocol must be easily adaptable to various states, to accommodate existing state data management systems.

Characterization of Contamination Potential from Class II Wells

The characterization of the contamination potential from Class II injection operations involves identification of potential contamination pathways, definition of the factors affecting risk of contamination for each pathway, identification of possible data sources for each risk factor, and characterization of the comparative importance of each factor affecting risk. Once these steps have been completed, a methodology to compute the relative risk of USDW contamination based on the identified risk factors can be developed.

Potential Contamination Pathways

Previous risk assessment efforts have focused on a single contamination pathway such as corroded casing or abandoned wells serving as the conduit for brine migration. To provide a comprehensive assessment of the risk, it is necessary to define the universe of potential pathways for contamination of a USDW from oil and gas injection operations. After considering possible well construction configurations, the potential contamination pathways can be simplified in a matrix such as that shown in Figure 1. Movement of brine from the injection zone to a USDW could occur either outside the casing or inside the casing. The factors associated

Figure 1

Universe of Potential Contamination Pathways

	Outside Casing (Cement Failure)	**Inside Casing (Casing/Tubing Failure)**
Disposal Well		
Production/Injection (EOR) Well		
Abandoned Well		

with each of these would be dependent upon whether the well was a disposal well, a production/injection (EOR) well, or an abandoned well. An uncased abandoned well could fall into either of the bottom cells in the matrix with the factors altered to reflect absence of cement or casing rather than failure.

Factors Affecting Risk

The six cells shown in Figure 1 describe the potential means for brine to reach and contaminate a USDW. However, many factors would affect whether contamination could occur through each pathway described. Some factors would be common to all cells of the matrix, while others would be unique to a single cell. The factors associated with each cell will be used to define the risk of contamination through that potential pathway. Table 1 presents a preliminary list of the factors associated with each cell of the matrix. Data values may not be required for all of the risk factors included in Table 1, but in identifying those most important to the relative risk of contamination, it is important to consider broadly what factors may affect risk.

Potential Data Sources

The next step in characterizing the potential risk associated with Class II injection is to identify possible data sources for the risk factors in each cell of the matrix. This process will identify which data items are readily available from state data management systems (drawing on the needs assessment work for UIPRF), and other public and private information sources. In many states, existing data management systems contain much of the information needed to estimate the risk, including mechanical integrity test histories, injection rates and pressures, depths, and well construction. Aquifer data can be difficult to obtain; however, in the needs assessment survey, 17 of 25 states contacted reported having data on the general location and depth of aquifers. In other states aquifer information may be available from water well operators, examination of well logs for producing wells in the area, or from the U.S. Geological Survey.

For data items which are not readily available, analogs from available information, engineering "rules of thumb," or computer regressions/simulations will be developed. Many data parameters (such as corrosion potential or density of abandoned wells) have been estimated on a more aggregate basis (see Michie, 1988 and Gruy, 1989). These data could be used in a risk assessment if more area-specific (field-specific) information was not available. Potential state-specific sources of information will be documented as part of the implementation guidelines provided to states with the risk assessment protocol.

Table 1

Major Risk Factors for Each Potential Contamination Pathway

Contamination from Outside Casing in a Disposal Well

- Pressure in disposal formation
  - Depth
  - Volume of injected fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and disposal formation
- Quality of cement job
  - Age of well
  - Hole size and casing size
  - Formation type
  - Type and volume of cement pumped
  - Pressure test results (direct measure of communication)
  - Cement bond log results (direct measure of micro-annulus or channeling)
- Number/density of disposal wells

Contamination from Outside Casing in a Production/Injection Well

- Pressure in injection formation
  - Depth and/or degree of over or under pressure (if any)
  - Volume of injected fluids or produced fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and injection formation

Quality of cement job

Table 1 (Continued)

Major Risk Factors for Each Potential Contamination Pathway

Contamination from Inside Casing in Disposal Well

- Pressure in disposal formation
  - — Depth
  - — Volume of injected fluids
  - — Capacity of formation (kh)
- Pressure in USDW
  - — Depth
  - — Degree of depletion/recharge
- Vertical distance between USDW and disposal formation
- Completion configuration
  - — Tubingless or packerless
    - Number of casing strings
    - Age of well
    - Production history (pressure, sand, rates)
    - Produced fluid corrosivity (CO_2, H_2S)
    - USDW water composition
    - Casing strength, material, condition (new or used), size
  - — Tubing and packer
    - All factors identified for tubingless or packerless
    - Tubing strength, material, condition (new or used), size
    - Packer type
    - Type of annular fluid
  - — Annular disposal
    - All factors identified for tubing and packer
    - Surface pressure on annulus/injection rate
- Use of cathodic protection
- Number/density of disposal wells

Contamination from Inside Casing in Production/Injection Well

- Pressure in injection formation
  - — Depth and/or degree of over or under pressure (if any)
  - — Volume of injected fluids
  - — Capacity of formation (kh)
- Pressure in USDW
  - — Depth
  - — Degree of depletion/recharge
- Vertical distance between USDW and injection formation
- Completion configuration
  - — Tubingless or packerless
    - Number of casing strings
    - Age of well
    - Production history (pressure, sand, rates)
    - Produced fluid corrosivity (CO_2, H_2S)
    - USDW water composition
    - Casing strength, material, condition (new or used), size
  - — Tubing and packer
    - All factors identified for tubingless or packerless
    - Tubing strength, material, condition (new or used), size
    - Packer type
    - Type of annular fluid
  - — Annular disposal
    - All factors identified for tubing and packer
    - Surface pressure on annulus/injection rate
- Use of cathodic protection
- Number/density of production/injection wells

Table 1 (Continued)

Major Risk Factors for Each Potential Contamination Pathway

Contamination from Inside Casing in Abandoned Wells

- Pressure in disposal/injection zones penetrated by abandoned well
  - — Depth
  - — Volume of injected fluids
  - — Capacity of formation (kh)
- Pressure in USDW
  - — Depth
  - — Degree of depletion/recharge
- Vertical distance between USDW and disposal/injection formation
- Abandoned well characteristics
  - — Age
  - — Plugging/casing/completion practices
  - — Plugging materials
  - — Annular fluid
- Corrosion potential
- Number/density of abandoned wells
- Distance from disposal/injection well

Importance of Each Factor

Information must also be developed on the relationships between the risk factors identified and the comparative importance of each factor to the potential for contamination. In addition to articles in the literature, potential data sources include oilfield service companies, producing companies, and state regulators' experience. Consultations with field personnel should yield insight into the relationships between the various factors that can be used in constructing the analytical methodology.

To the extent possible, the relationships developed will be based on field experience with mechanical integrity or cement failures where no groundwater contamination occurred. Analysis of the conditions that prevented contamination is the best source of information about which factors are most important to the risk of contamination. Pressure differentials between the injection formation and the USDW that would allow or prohibit upward movement of brine are clearly the most important risk factor in most cases. Rankings of the relative importance of other risk factors will be developed using historical data (with regressions or simulations as appropriate) as well as standard engineering correlations and the judgment and extensive field experience of oil and gas company personnel, service company personnel and state regulators. Assumptions made about the relationships between and comparative importance of risk factors in the analysis will be made explicitly and documented; users of the protocol will be able to adjust these assumptions to the needs of a particular state or to test an alternative assumption.

Computation of Relative Risk

Risk will be defined as a function of the risk factors identified, using the comparative importance relationships developed. Some of the risk factors will be measured quantitatively (such as pressure differential or vertical distance brine must travel), while others will be qualitative (such as the quality of the cement job or use of cathodic protection). Qualitative measures will be converted to a numerical scale to provide a common basis for combining diverse information in an equation to calculate risk. The relative importance of each risk factor will provide the weighting for each term in the equation in developing the protocol. Another important consideration in the development of the protocol is the uncertainty associated with parameter estimates (both the areal estimates input by the user and the factor relationships developed). The effect of this uncertainty on the level of confidence in the result must be addressed. The risk assessment protocol will identify the relative risk on a numerical scale (e.g., 1 to 5). A scale of this type will provide the type of comparability among pathways/areas desired in a format that is easy to understand and is appropriate for the variability and ranges of uncertainty involved.

The risk assessment protocol will calculate the relative risk of contamination two ways: (1) for each potential pathway of contamination (cells in the matrix), and (2) for the area as a whole considering all potential contamination pathways. The relative risk of contamination in an area through each of the potential contamination pathways will be useful to states in identifying priorities within an area. These relative risk ratings will also be combined to develop a single risk assessment for an area which will allow various areas to be compared in setting state-wide priorities or establishing a variance program.

Development of Risk Assessment Protocol

Development of the risk assessment protocol will follow the steps outlined above for identifying data sources and developing relationships among the risk factors so that the relative risk of contamination can be calculated. Several alternative statistical techniques will be evaluated for developing the protocol and for accounting for uncertainty.

In developing the risk assessment protocol, ICF Resources will work extensively with state regulators to assure that the system addresses their concerns and provides useful results. ICF Resources will also work with on-going data management efforts to address risks from UIC to assure the compatibility and maximize the utility of the protocol to the states.

Format for Protocol

The platform on which the protocol is to be designed has not been determined. The risk assessment protocol will be IBM or compatible PC-based and will use commercial software or stand alone. Several commercial software packages are being considered, including Lotus 1-2-3 and dBase III/IV. The objective is to make the system easy to use and adaptable, with the assumptions explicit, easily modified, and thoroughly documented.

Testing and Sensitivity Analysis

Field testing of the risk assessment protocol will be conducted in cooperation with 1 or 2 states, perhaps reflecting states with and without well-established data management capabilities. The expertise of the regulators in these states will be solicited throughout the development process, as well as in testing and validation of the protocol. Calibration of the protocol will be subjective because (1) the paucity of actual contamination occurrence data makes history matching impossible, and (2) many of the risk factor relationships may be subjective rather than empirical.

Sensitivity analyses will be run as part of the testing and validation process to identify factors or assumed relationships with the greatest impact on the result. These factors and relationships will determine areas where better data or further study may be required to increase the confidence level of the resulting risk assessment.

Schedule for Completion

The design phase of this project is just being completed. States participating in the development and testing phases of the project will be identified within the next month. Information collection for several aspects of the development has already started and will continue over the next two months. Development and testing of the risk assessment protocol is expected to be complete by April 1993.

Conclusions

A risk assessment protocol for characterizing the relative risk of groundwater contamination from Class II injection operations provides an explicit means for incorporating risk-based decision-making into current state regulatory and data management programs. A risk assessment protocol can be used for exempting wells with a low risk of contamination from a potential extension of current AOR requirements or for prioritizing and justifying state activities, including:

- Increased field activity monitoring
- Inclusion of fields in a computerized data management system
- Collection of additional injection and production-related information.

The value of incorporating risk-based decision-making into state UIC programs is obvious. An explicit methodology that provides a comprehensive assessment of the potential risk of contamination from all possible pathways is an appropriate tool for incorporating risk, and can generate benefits by allowing limited resources to be focused on those areas where they can have the greatest impact on reducing contamination risks.

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